

The EMC Effect and Short-Range Correlations

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Abstract. We overview the progress made in studies of EMC and short range correlation (SRC) effects with the special emphasis given to the recent observation of the correlation between the slope of the EMC ratio at Bjorken $x < 1$ and the scale factor of the same ratio at $x > 1$ that measures the strength of the SRCs in nuclei. This correlation may indicate the larger modification of nucleons with higher momentum thus making the nucleon virtuality as the most relevant parameter of medium modifications. To check this conjecture we study the implication of several properties of high momentum component of the nuclear wave function on the characteristics of EMC effect. We observe two main reasons for the EMC-SRC correlation: first, the decrease of the contribution from the nuclear mean field due to the increase, with A , the fraction of the high momentum component of nuclear wave function. Second, the increase of the medium modification of nucleons in SRC. Our *main prediction* however is the increase of the proton contribution to the EMC effect for large A asymmetric nuclei. This prediction is based on the recent observation of the strong dominance of pn SRCs in the high momentum component of nuclear wave function. Our preliminary calculation based on this prediction of the excess of energetic and modified protons in large A nuclei describes reasonably well the main features of the observed EMC-SRC correlation.

Keywords: EMC effect, Parton Distributions, Short Range Correlations

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The EMC Effect: The discovery of the nuclear EMC effect[1] is one of the unique cases in which the explicit degrees of QCD is intertwined with the picture of nucleus consisting of hadrons. However the specific dynamics of the modification of partonic distributions (PDFs) in bound nucleon have not yet been identified with certainty. The quantity under consideration is the ratio of inclusive cross sections of nuclei A and deuteron measured in deep inelastic kinematics at $x < 1$ (corrected by the factor, f which accounts for the unequal numbers of protons and neutrons):

$$R_{EMC}(x, Q^2) = \frac{2 \cdot \sigma_{eA}}{A \cdot \sigma_{ed}} f(x, Q^2). \quad (1)$$

Since R_{EMC} is measuring the ratio of nucleon PDFs in A and the deuteron it was expected that $R_{EMC} = 1$. However the first experiments[1, 2] found it substantially less than unity in the region of $0.3 < x < 0.8$. Later experiments[3] were able to quantify the magnitude of the EMC effect as proportional to A or to the average nuclear density defined as $\rho(A) = 3A/4\pi R_e^3$, with $R_e^2 = 5\langle r^2 \rangle/3$, where $\langle r^2 \rangle$ is the nuclear RMS radius measured in elastic eA scattering. The recent measurements of EMC effects at Jefferson Lab reached to unprecedented accuracy[4]. These measurements demonstrated that the early observation of the proportionality of the EMC effect to average nuclear density is not valid, with ${}^9\text{Be}$ nucleus clearly out of sync with other nuclei. However the simple monotonic A dependence agreed well with the all measured nuclei. Thus these measurements demonstrated that for the EMC effect the A and average density dependences are not equivalent. Another result of the new experiment was the observation of

no Q^2 dependence of the depletion of R_{EMC} for $4 < Q^2 < 6 \text{ GeV}^2$. The parallel theoretical development in EMC studies was the realization that due to the charge Z the nucleus has a Coulomb field which in the reference frame in which the nucleus has a large momentum is transformed into the field of equivalent photons. If $Z\alpha_{em}$ is not small then the equivalent photons carry finite fraction of nuclear momentum. The account of this momentum fraction in heavy nuclei as compared to the deuteron removed some of the EMC effect for medium to heavy nuclei at $0.3 < x < 0.5$ region. Thus the genuine medium modification is associated with the depletion of the nuclear structure function only in $0.5 < x < 0.8$ region[5].

Summarizing, the latest progress in EMC studies indicates that; (a) the size of the effect is proportional to A but not to the average nuclear density; (b) the account for the Coulomb effects narrows the range of the EMC effect to $0.5 < x < 0.8$, the region corresponding to the scattering off the bound nucleon with large initial momenta; (c) no apparent Q^2 dependence is observed for $4 < Q^2 < 6 \text{ GeV}^2$ which may provide important constraint on the potential mechanism of EMC effects.

Short Range Nucleon Correlations in Nuclei: SRCs are considered one of the most elusive features of the ground state nuclear wave functions. It is expected not to be probed directly with any low energy probe. However advent of the high energy probes allowed a significant progress in isolating and studying the dynamical nature of 2N SRCs (for recent reviews see [6, 7]). One of the methods in probing 2N SRCs is studying high Q^2 inclusive $A(e, e')X$ scattering at $x > 1.4$ in which case virtual photon scatters off the bound nucleon with momenta exceeding $k_F(A)$ [9, 12]. If the scattering indeed happens with the nucleon from 2N SRC then the prediction is that the ratio of the inclusive cross sections of nucleus A and the deuteron should exhibit a plateau[10, 11]. Such a plateau was observed in both SLAC[11] and recent JLab[13, 14] measurements. Another recent news from SRC studies is the observation of a strong (by factor of 20) dominance of pn relative to pp and nn SRC's in the range of the bound nucleon momenta $k_F < p < 600 \text{ MeV}/c$ [15, 16]. This observation was an indication that at the distances relevant to the above momentum range the NN force is dominated by tensor interaction. This gave a new meaning to the above mentioned ratios:

$$a_2(A) = \frac{2 \cdot \sigma_{eA}}{A \cdot \sigma_{ed}}, \quad (2)$$

which now represent (up to the SRC center of mass motion effect) the probability of finding 2N SRCs in the nucleus A . The observed strong disbalance of pn and pp/nn SRCs allowed also to suggest new approximate relation for the high momentum distribution of protons and neutrons in the nucleus A [8]:

$$n_{p/n}^A(p) = \frac{1}{2x_{p/n}} a_2(A, y) \cdot n_d(p) \quad (3)$$

where $x_{p/n} = \frac{Z}{A} / \frac{A-Z}{A}$ and $y = |1 - 2x_p|$. According to this relation one expects *more* energetic protons than neutrons in nuclei with an excess of neutrons ($x_n > x_p$). In the recent study[8] the analysis of the existing data demonstrated that $a_2(A, y)$ is proportional to A and decreases with an increase of nuclear asymmetry ($y \rightarrow 1$).

Summarizing, the recent SRC studies indicate that, (a) $a_2(A, y)$ is proportional to A and (b) for large A due to the excess of neutrons more protons occupy the high momentum tail of the momentum distribution than neutrons.

A	$P_p(\%)$	$P_n(\%)$	A	$P_p(\%)$	$P_n(\%)$
12	20	20	56	27	23
27	23	22	197	31	20

Correlation between EMC and SRC Effects: One of the most intriguing recent observations is the apparent correlation between the strength of the EMC effects (measured as $-dR_{EMC}/dx$) and the strength of the SRCs (measured through a_2). The initial observation[19] was that the correlation is purely linear, however the most recent measurements indicate on possibly of non-linearity in these correlations[20]. To understand the reason for such correlation we explore two possibilities; (a) it is the reflection of the fact that larger is a_2 smaller is the overall normalization of the mean-filed part of the momentum distribution and so is R_{EMC} due to sizable mean-field contribution to the DIS cross section at $x < 1$ and (b) if EMC effect is only due to the high momentum component of nuclear wave function then large a_2 will correspond to more medium modification therefore to smaller R_{EMC} .

In the case of (b) in calculations it is important to take into account Eq.(3) according to which protons and neutrons will have different amount of high momentum components in asymmetric nuclei. In the table we present the overall fractions of high momentum ($> k_F$) protons and neutrons estimated according to Eq.(3). This result indicates that for large A the protons in average will be more energetic and virtual. Since at $x > 0.5$ proton DIS structure functions are larger than that of neutron and if EMC effect is proportional to the nucleon virtuality, then we predict that the most of the EMC effect will be due to proton modification in the medium

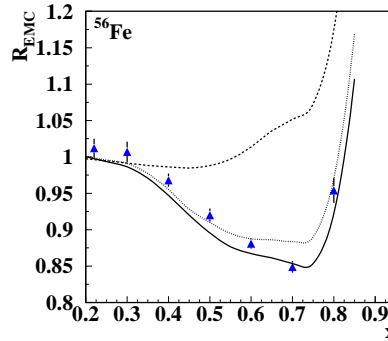


FIGURE 1. The x dependence of R_{EMC} for ^{56}Fe nucleus.

The EMC Model: To be able to check the above conjectures we need to estimate R_{EMC} within the model in which the effect is proportional to the virtuality of bound nucleon. This model is developed based on the light cone (LC) approximation of deep inelastic eA scattering in which nuclear DIS structure function is expressed as[10, 17]:

$$F_2^A(x, Q^2) = \sum_{N=1}^A \int_x^A \frac{d\alpha}{\alpha} F_{2N}^{bound}\left(\frac{x}{\alpha}, Q^2\right) n_N^A(\alpha), \quad (4)$$

where α is (A times) the LC momentum fraction of the nucleus carried by the bound nucleon. In the nuclear LC density matrix, $n_N^A(\alpha)$, the high momentum component is

constructed according to 2N SRC model (Eq.3) which contains the above mentioned asymmetry for protons and neutrons. The DIS structure function of the bound nucleon $F_{2N}^{bound}(x, Q^2)$ contains all the effects due to nuclear modification.

For the nuclear modification we consider the color screening model[18] which is based on the observation that the most significant EMC effect is observed at large $x > 0.5$ corresponding to high momentum component of the quark distribution in the nucleon, in which three quarks are close together in point-like configurations (*PLC*). It is then assumed that the dominant contribution to $F_{2N}^{bound}(x, Q^2)$ is given by *PLCs* which, due to color screening, interact weakly with the other nucleons. As a result the optimally bound configuration of nucleons will have suppressed contribution from the PLC component of nucleon wave function. This suppression of *PLC* in a bound nucleon is assumed to be the main source of the *EMC* effect in inclusive *DIS*. The suppression factor is calculated in perturbation series of the parameter: $\kappa = \left| \frac{\langle U_A \rangle}{\Delta E_A} \right|$, where $\langle U_A \rangle$ is the average nuclear potential energy per nucleon and $\Delta E_A \approx M^* - M \sim 0.6 \div 1 \text{ GeV}$ is the typical energy for nucleon excitations within the nucleus. The *PLC* suppression can be represented by a multiplicative factor $\delta_A(k^2)$ to $F_2^N(x, Q^2)$ that enters in Eq.4[18]:

$$\delta_A(p^2) = \frac{1}{(1 + \kappa)^2} = \frac{1}{[1 + (p^2/M + 2\varepsilon_A)/\Delta E_A]^2}, \quad (5)$$

where p is the momentum of the bound nucleon in the light cone.

Using the above estimate of the suppression factor we present in Fig.1 the comparison of our calculations[21] of R_{EMC} for ^{56}Fe with the data[3]. As the comparisons show the prediction of LC dynamics (dashed curve), in which no medium modifications are accounted for, grossly overestimates R_{EMC} . The dash-dotted curve accounts for the medium modification effects only due to the nuclear mean field and the solid line includes, in addition, the modification of the nucleon DIS structure function in SRC. As the figure shows the modification in SRC becomes increasingly important at $x > 0.5$. It is worth noting that the present calculations are preliminary and does not account for the effects due to the Coulomb field[5] discussed earlier. The latter effect as expected will shift the EMC strength towards higher $x(> 0.5)$ thereby enhancing the role of the nucleon modifications in SRC.

Finally we used our model[21] to calculate the correlation between $-dR_{EMC}/dx$ and a_2 . Our preliminary calculation (Fig.2) describes the correlation observed in Ref.[20] surprisingly well. Both, mean field depletion due to SRC and large medium modification in the SRC contribute to the calculated correlation. We predict nonlinear correlation and the main reason of this is the enhancement of the proton contribution in the EMC effect due to the increase of their average momenta in large A asymmetric nuclei (as it was discussed above). Note that the Coulomb effects will change the current result slightly, since our main effect is due to SRC which is dominated at large $x > 0.5$.

Conclusion and Outlook: We present the first attempt to quantify the observed correlation between the strengths of the EMC effect and SRCs. Our calculations show that two main factors contribute to this correlation. One, with the increase of a_2 the normalization of the mean-field part of the nuclear wave function is decreasing which results to the depletion of R_{EMC} . Second, at $x > 0.5$ the modification of the nucleons in the SRC plays increasingly important role and in all models in which the EMC effect is proportional to nucleon virtuality the large effect of the EMC will be correlated to

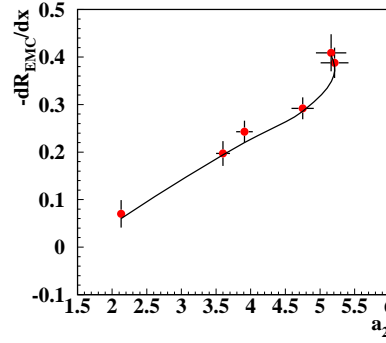


FIGURE 2. Correlation between the EMC slope and SRC strength.

the large value of $a_2(A)$. Finally we predict large EMC effect due to the increased proton contribution to R_{EMC} for large A asymmetric nuclei. This predication allows us to describe the non-linearity of the EMC-SRC correlation at large A.

The new prediction of the increased role of the protons in the EMC effect can, in principle, be checked in deep inelastic semi-inclusive $(A(e, e'N)X)$ reactions in which the spectator nucleon is detected in the backward hemisphere of the reaction which minimizes the final state interaction effects[22, 23, 24].

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